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Source rock characteristics and hydrocarbon generation modelling of Upper Cretaceous Mukalla Formation in the Jiza-Qamar Basin, Eastern Yemen

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ABSTRACT

The Upper Cretaceous Mukalla coals and other organic-rich sediments which are widely exposed in the Jiza-Qamar Basin and believed to be a major source rocks, were analysed using organic geochemistry and petrology. The total organic carbon (TOC) contents of the Mukalla source rocks range from 0.72 to 79.90% with an average TOC value of 21.50%. The coals and coaly shale sediments are relatively higher in organic richness, consistent with source rocks generative potential. The samples analysed have vitrinite reflectance in the range of 0.84–1.10 %Ro and pyrolysis T_{max} in the range of 432–454 °C indicate that the Mukalla source rocks contain mature to late mature organic matter. Good oil-generating potential is anticipated from the coals and coaly shale sediments with high hydrogen indices (250–449 mg HC/g TOC). This is supported by their significant amounts of oil-liptinite macerals are present in these coals and coaly shale sediments and Py-GC (S_2) pyrograms with *n*-alkane/alkene doublets extending beyond nC_{30}. The shales are dominated by Type III kerogen (HI < 200 mg HC/g TOC), and are thus considered to be gas-prone.

One-dimensional basin modelling was performed to analysis the hydrocarbon generation and expulsion history of the Mukalla source rocks in the Jiza-Qamar Basin based on the reconstruction of the burial/thermal maturity histories in order to improve our understanding of the of hydrocarbon generation potential of the Mukalla source rocks. Calibration of the model with measured vitrinite reflectance (Ro) and borehole temperature data indicates that the present-day heat flow in the Jiza-Qamar Basin varies from 45.0 mW/m^2 to 70.0 mW/m^2 and the paleo-heat flow increased from 80 Ma to 25 Ma, reached a peak heat-flow values of approximately 70.0 mW/m^2 at 25 Ma and then decreased exponentially from 25 Ma to present-day. The peak paleo-heat flow is explained by the Gulf of Aden and Red Sea Tertiary rifting during Oligocene-Middle Miocene, which has a considerable influence on the thermal maturity of the Mukalla source rocks. The source rocks of the Mukalla Formation are presently in a stage of oil and condensate generation with maturity from 0.50% to 1.10% Ro. Oil generation (0.5% Ro) in the Mukalla source rocks began from about 61 Ma to 54 Ma and the peak hydrocarbon generation (1.0% Ro) occurred approximately from 25 Ma to 20 Ma. The modelled hydrocarbon expulsion evolution suggested that the timing of hydrocarbon expulsion from the Mukalla source rocks began from 15 Ma to present-day.

1. Introduction

Yemen's main sedimentary basins are the Marib-Shabowah Basin, the Masila Basin, and the Jiza-Qamar Basin (Fig. 1). To date, only two onshore basins contain proven commercial quantities of oil and gas. In the western part of Yemen, oil and gas are produced from the Marib-Shabowah Basin, while in the eastern part of Yemen the Masila Basin has produced mainly oil and some gas (Beydoun, 1989, 1991; Bosence, 1997). The study area for this paper lies in the Jiza-Qamar Basin in the east of Yemen focussing on the Qamar sector (Fig. 1). The Jiza-Qamar Basin is undergoing hydrocarbon exploration and research since the significant hydrocarbon potential still poorly. Of the 5 exploratory wells drilled in the Qamar sector of the Jiza-Qamar Basin by the Nimir Agip Oil Companies, minor oil shows were encountered in only two of the wells.

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The poor knowledge of the evolution of the subsurface rocks in the Jiza-Qamar Basin, especially with respect to the characteristics and the depositional conditions of the organic matter within the potential source rocks may have been responsible for the unsuccessful exploration attempts within the basin. Although, few studies had been undertaken on the basin's source rock potential and organic matter (OM) maturity (Alaug, 2011a,b), detailed organic geochemical and petrographic investigations on the origin of organic matter, and their thermal/burial histories, and the timing of hydrocarbon generation and expulsion are lacking. However, most of the previous studies within the analysed basin have established the potential source rocks in the study area, but have not conducted the source rock maturity and the timing of hydrocarbon generation and expulsion modelling. Basin modelling in exploration related studies is still a relative young but extremely useful discipline to reveal the timing, and to understand and quantify the complex processes of petroleum formation (Waples, 1994; Burrus et al., 1991; Hermanrud, 1993; Littke et al., 1994; Hakimi et al., 2010b; Shalaby et al., 2011). The corporation of source rock characteristics into basin modelling can give more detailed information needed to answer exploration questions on hydrocarbon generation and expulsion of the source rocks.

This current study focuses on the detailed geochemistry and organic petrographic of the Mukalla Formation, to provide an overview of the organic richness, hydrocarbon generation potential and level of maturity of the organic matter in the Mukalla sediments. In addition, the results of source rock characteristics are incorporated into basin modelling in order to know and determine the timing of hydrocarbon generation and expulsion of the Mukalla source rocks. This is aimed at re-appraising and validating the potentials of the formation as effective source rock, and hence ultimately provides further insight into the source rocks of the basin, for future petroleum exploration programme and resource assessment in the basin.

2. Geologic setting

The geological evolution of Yemen was driven by the plate motions that broke southern Gondwana apart in the Mesozoic and formed the Gulf of Aden and Red Sea in the Cenozoic (Redfern and Jones, 1995; Beydoun et al., 1998; Csato et al., 2001). The Jiza-Qamar Basin is situated in Eastern Yemen with extending into Oman and is one of the Mesozoic sedimentary basins of Yemen (Fig. 1). The basin was formed as a rift-basin linked to the Mesozoic breakup of Gondwanaland and the evolution of the Indian Ocean during the

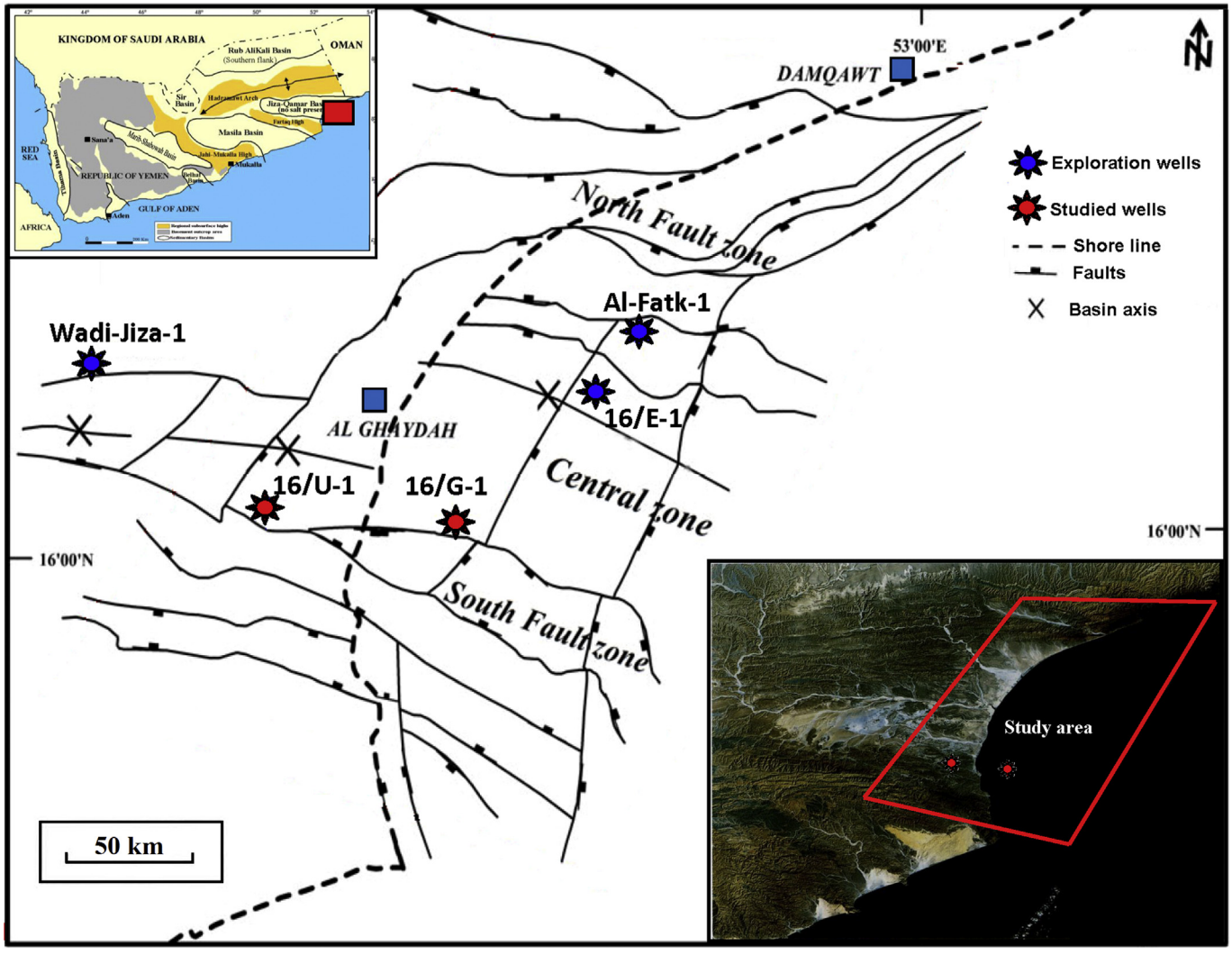

Figure 1. Main sedimentary basins in Republic of Yemen (modified after Beydoun et al., 1998) showing location map of the Jiza-Qamar Basin and the studied wells.